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New Claims

1. A method for producing a micro and/or nanostructure for modulating light, comprising the steps of:

providing a theoretical simulation of light modulating parameters for the structure, the simulation being based on an exact numerical calculation of fields within the structure and outside a light emitting surface of the structure;

characterizing the emitting surface of the structure by geometric and light profiling at the surface, in the near-field of the surface, and at far-field distances from the surface; and

fabricating the nanostructure emitting surface integrally with said simulation and characterization steps.

2. The method of claim 1, wherein fabricating said structure includes forming an emitting surface on the end of an optical fiber, hollow fiber, or other waveguide.

3. The method of claim 1, wherein light profiling at the emitting surface includes determining the properties of light emitted from the structure.

4. The method of claim 1, wherein geometric profiling includes scanned probe topographic imaging.

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5.   The method of claim 1, further including fabricating the nanostructure to produce a waveguide having a light emitting surface and guiding the fabrication by said simulation and characterization steps.

6.   The method of claim 5, wherein fabricating the nanostructure includes forming the emitting surface on the end of an optical fiber, hollow fiber, or other waveguide.

7.   The method of claim 6, wherein light profiling at the emitting surface includes determining the properties of light emitted from the emitting surface.

8.   The method of claim 7, wherein geometric profiling includes scanned probe topographic imaging.

9.   The method of claim 7, further including controlling the fabrication of said structure and said emitting surface by integrating the theoretical simulation, the characterization, and the fabrication steps.

10.   The method of claim 1, further including characterizing the mode field diameter of said structure or the spot size produced by light emitted from said emitting surface for optically coupling the structure to another optical device.

11.   The method of claim 1, wherein fabricating the emitting surface includes forming a lens.

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12. The method of claim 1, wherein providing a simulation includes analyzing coupling efficiency, beam waist diameter and working distance taper angle for light emitted from said structure, and determining radius of curvature for said emitting surface for designing an optimal structure.

13. The method of claim 1, wherein providing a theoretical simulation includes finite element field calculations, and wherein characterizing the emitting surface includes monitoring the fabrication of the nanostructure using near-field and far-field optical characterization with scanned probe imaging.

14. The method of claim 1, wherein said theoretical simulations include interactively defining boundary conditions by near-field optics to provide said exact field calculations.

15. The method of claim 1, wherein fabricating the nanostructure includes pulling; mechanical, laser or heat polishing; etching, writing, imprinting or molding; or deposition processes.

16. The method of claim 1, wherein characterizing the emitting surface includes determining the phase properties of light within the structure and of light emitted from the emitting surface.

17. The method of claim 16, wherein characterizing the emitting surface further includes atomic force topographic imaging of the surface.

18. The method of claim 16, wherein characterizing the emitting surface further includes measuring light emitted from the surface for return loss, polarization dependent loss, and/or coupling efficiency.

19. The method of claim 1, wherein characterizing the emitting surface includes characterizing the mode field diameter, spot size, and beam waist diameter of emitted light and the working distance taper angle and radius of curvature of the emitting surface.

20. The method of claim 1, further including interactively providing said theoretical simulation, characterizing, and fabricating the emitting surface to provide micro-optical structures for emitting light at wavelengths of about 1.5μ with a waist diameter of about 1.6μ.

21. The method of claim 1, wherein the step of fabricating includes fabricating converters, couplers, multi-lens arrays and microelectro-mechanical devices.

22. The method of claim 1, wherein the step of providing a theoretical simulation includes adjusting theoretical parameters in response to the characterization of the emitting surface.

23. The method of claim 1, wherein the fabrication step is selected on the basis of said theoretical simulation and characterization steps to achieve a desired distribution of emitted light and to obtain desired topographic measurements,

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far-field measurements, return loss, polarization loss, and/or coupling efficiency.

24.   The method of claim 1, wherein characterizing emitted light in the near field of the emitting surface includes providing a near-field optical aperture having a diameter as small as 1/10 the wavelength of the emitted light at a distance as close as 1/10 the wavelength of the emitted light from the emitting surface, and monitoring the light passing through said aperture.

25.   The method of claim 24, further including monitoring the wavefront of emitted light at multiple optical planes to determine phase properties and/or phase-based properties of the emitted light.

26.   The method of claim 24, further including near-field characterization of emitted light with said near field aperture using differential interference contrast measurements.

27.   The method of claim 24, further including providing, from said aperture, a stable source of light for providing a point spread function for a far-field optical imaging system.

28.   The method of claim 27, further including characterizing emitted light by differential interference contrast measurement to improve resolution.

29. The method of claim 28, further including interactively determining the exact three-dimensional position of the aperture and characterizing the emitted light for each position, and adjusting the theoretical simulations to define the optical properties of the emitting surface.

30. The method of claim 1, wherein the step of fabricating includes tapering and polishing or etching a waveguide to produce said emitting surface on an end of the waveguide, said emitting surface comprising a lens having a radius of curvature and a tapering angle to focus light emitted by the waveguide, said light having a selected waist diameter.

31. The method of claim 30, wherein said waveguide is an optical fiber having a core and cladding, wherein tapering includes tapering both the core and the cladding and wherein etching or polishing alters only the cladding.

32. The method of claim 31, where tapering the core is independent of tapering the cladding, and wherein the lens parameters are dependent on core taper angle, cladding taper angle, and radius of curvature of the cladding.

33. The method of claim 30, wherein tapering of said fiber includes laser heating of the fiber with defined tension and defined cooling based on said near-field optical characterization and interactive theoretical simulations.

34. The method of claim 33, further including shaping said lens to control the focal spot of emitted light to a diameter of about 0.25μ for wavelengths of about 1.3-1.6μ.

35. The method of claim 1, wherein the step of fabricating includes pulling an optical fiber to produce an axial protrusion at the end of the fiber, and controlling the shape of the protrusion by iterative characterization of the protrusion and comparison with the theoretical simulation of the protrusion structure to form a lens.

36. The method of claim 35, wherein the step of fabrication further includes etching and thereafter melting said protrusion to modify the curvature of the protrusion to form a lens having desired parameters.

37. The method of claim 36, wherein melting includes laser ablation of fiber cladding to produce a stripped fiber.

38. The method of claim 35, wherein the fiber is fabricated to direct light exciting the fiber at an angle relative to the direction of the fiber axis.

39. The method of claim 35, wherein fabricating includes forming a cylindrical lens.

40. The method of claim 39, further including further shaping the cylindrical lens to form an elliptical lens.

41. The method of claim 35, wherein fabricating includes preserving the polarization of light emitted at said emitting surface.

42. The method of claim 35, further including stripping the fiber and thereafter selectively coating the fiber and/or lens.

43. The method of claim 42, wherein coating includes metal deposition.

44. The method of claim 42, wherein coating includes deposition of metal on said fiber and said lens, and further including forming an aperture in the metal coating on said lens.

45. The method of claim 44, wherein forming an aperture includes nanoindentation, ion beam etching, chemical etching, or femtosecond laser nonlinear ablation, or a combination thereof.

46. The method of claim 1, wherein the step of fabrication includes forming a waveguide incorporating said emitting surface at one end, said emitting surface being shaped in response to iterative theoretical simulation and characterizing to produce a lens structure.

47. The method of claim 1, wherein the step of fabrication includes forming a waveguide incorporating said emitting surface, and further including forming on said emitting surface Fresnel and/or diffractive optics.

48. The method of claim 47, wherein said fiber is moved with respect to a near-field optical tip through which a laser is directed onto said emitting surface to

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alter the index of refraction at said surface with a resolution sufficient to form a Fresnel lens or a diffractive optical pattern.

49. The method of claim 47, further including altering the refractive index and/or the topography of said waveguide by laser or chemical etching, atomic force lithography or focused ion beam etching with sufficient resolution to produce said Fresnel or diffractive lens.

50. The method of claim 1, wherein the step of fabrication includes forming a waveguide having a core and having an emitting surface, and further including forming a diffraction pattern on the core to alter the index of refraction or topography of the core to focus emitted light, to compensate for light dispersion, to produce phase front correction in emitted light, to remove or impose birefringence, or to remove lens aberrations.

51. The method of claim 50, wherein forming a diffraction pattern includes:

coating an end of said waveguide core with metal and dialectric layers;

forming an aperture in said layers;

directing light through said aperture; and

manipulating the light, the thickness and number of metal and dialectric layers being matched to the wavelength of light to be manipulated.

52. The method of claim 1, wherein the step of fabricating includes forming a Bragg grating on said emitting surface.

53. The method of claim 1, wherein the step of fabricating includes forming a solid immersion lens on a high index optical fiber.

54. The method of claim 53, wherein the step of forming a solid immersion lens includes:

   forming a ball on the end of the optical fiber; and

   polishing the ball to produce a flat head that serves as the lens.

55. The method of claim 54, wherein forming said lens includes iteratively providing a theoretical simulation of the lens structure and characterizing the structure as it is being fabricated.

56. The method of claim 55, wherein forming said lens further includes providing diffractive optics on the lens.

57. The method of claim 1, wherein the step of fabricating includes forming a ball lens on an optical waveguide.

58. A method for characterizing a waveguide structure, comprising:

   interactively measuring the refractive index of a medium; and

   modifying the refractive index of said medium.

59. The method of claim 58, wherein measuring the refractive index includes imaging the passage of light in said medium.

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60. The method of claim 59, wherein imaging the passage of light includes performing thermal conductivity or point thermocouple measurements.

61. The method of claim 59, wherein imaging the passage of light includes nanometric blocking in combination with far field image to detect variations in the intensity of light in said medium.

62. The method of claim 59, wherein imaging includes optical, electron optical, or ion optical imaging.

63. The method of claim 62, further including:

illuminating said medium;

correlating pixel for pixel the location on the surface of the medium of the imaging of the medium; and

comparing the measured refractive index with a theoretical simulation of the medium to obtain a refractive index profile of the medium.

64. The method of claim 62, further including:

further characterizing a light-emitting surface of said medium by light profiling in the near field; and

fabricating the light-emitting surface integrally with said imaging, with said characterizing and with simulating the parameters of the surface to provide a lens.

65. The method of claim 59, further including illuminating said medium through a near-field aperture to measure the index of refraction of the medium.

66. A method for light control in an optical waveguide, comprising:

forming a tapered hollow micropipette;

introducing a solution into the micropipette;

forming a metal nanoseed in said solution; and

growing the seed to produce a nanoparticle in the micropipette for

controlling light passing through the micropipette.

67. The method of claim 66, wherein forming a nanoseed includes inserting an end of the micropipette into a liquid for initiating seed formation.

68. The method of claim 67, further including pulling the micropipette out of the liquid at a rate controlled to produce a selected nanoparticle geometry at the end of the micropipette.

69. The method of claim 66, further including inserting a cooling liquid in said micropipette for cooling said nanoparticle.

70.   A method for forming an optical waveguide, comprising:

      filling a micropipette with a material having a selected index of refraction;

      causing a portion of said material to exit at the tip of the micropipette to produce a protrusion; and

      shaping the protrusion to form an optical element.

71.   The method of claim 70, further including coating the protrusion with metal and dielectric layers.

72.   The method of claim 70, further including:

      simulating the shape of the optical element to define its structure, refractive index, and light modulating properties;

      characterizing the optical element by geometric and light profiling at the surface of the optical element in the near field of the surface and at far-field distances from the surface; and

      iteratively shaping the element while simulating and characterizing its shape.

73.   A method for fabricating a lens, comprising:

      shaping a mold for use in forming a lens;

      simulating the shape of the mold to define the structure, refractive index, and light modulating properties of the lens to be formed in the mold;

      characterizing the shape of the mold by geometric and light profiling of the mold surface in the near field and the far field; and

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iteratively shaping the mold while simulating and characterizing its shape.

74. The method of claim 73, further including forming multiple molds for use in fabricating a micro lens array.

75. A method for producing an optical waveguide, comprising:

simulating the parameters of the waveguide on the basis of a calculation of fields within the waveguide structure and outside a light emitting lens on the waveguide;

characterizing parameters of the lens by near-field and far-field geometric and light profiling of the lens; and

iteratively fabricating the waveguide and lens integrally with said simulating and characterizing the lens parameters.

76. The method of claim 75, wherein the waveguide is a multimode optical fiber transmitter or coupler to a single mode structure, and wherein fabricating includes forming a tapered fiber and lens having a taper angle and radius of curvature, respectively, to provide a lens focus about 12 microns from the lens surface with a waist diameter of about 3.8 microns.

77. The method of claim 75, further including:

integrating said near-field and far-field characterizing steps for testing waveguides and lenses by mounting imaging devices for motion relative to the waveguide and lens being fabricated.

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78. The method of claim 71, further including modulating the motion of the imaging devices.

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